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International Journal of Disaster Risk Reduction 13 (2015) 167–188

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr

The adaptive governance of natural disaster systems: Insights from the 2010 mount Merapi eruption in Indonesia

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ARTICLE INFO

Article history:
Received 5 February 2015
Received in revised form
19 May 2015
Accepted 19 May 2015
Available online 22 May 2015

Keywords:
Adaptive governance
Adaptive capacity
Natural disasters
Qualitative analysis
Indonesia

ABSTRACT

An adaptive governance system strives to enhance the capacity of institutions to better coordinate relief operations, public awareness and risk reduction policy in case of natural or man-made disasters, by promoting learning from experience. The contribution of this article is twofold: (1) to establish an assessment framework for the adaptive capacity of a system in the field of disasters, and (2) to explore the governance system of Mt. Merapi volcano, Indonesia. We chose the Merapi volcano in the wake of the large 2010 eruption, the largest event over the past 140 years. We develop and apply an assessment framework for the adaptive capacity of a system with the following six key parameters: (1) system description, (2) technology, (3) infrastructure, (4) institutions, (5) information and skills, and (6) economic and financial resources. The methodology consists of a qualitative analysis, using a text analysis. The data have been collected from a field survey, which was conducted after the 2010 volcanic eruption and rain-triggered lahars on Mt. Merapi in central Java. We underline a number of challenges, such as apparent lack of appropriate infrastructures, complex interactions across institutions, dependence on funds from external parties, and limited quantitative documentation on both human and material loss, which may weaken the adaptive capacity of the system. More efforts are therefore needed in order to improve the adaptive capacity and, thus, the adaptive governance at Mt. Merapi. This study represents a significant step toward enhancing our understanding of the adaptive governance approach in developing countries.

1. Introduction

Natural hazards have the potential to impose significant social and economic costs. For the period 1980–2003, the Intergovernmental Panel on Climate Change [1] estimates that the economic loss due to natural disasters reached USD 1 trillion. We underline the difference between natural hazards, which are geophysical events such as volcanic eruptions, and disasters, which involve the interaction of natural hazards with social systems [2–7]. While hazards themselves cannot be prevented, the damage induced by these extreme events may be disastrous, if they cannot be significantly reduced. By "hazard", we mean a threat. Hazard is broadly defined as "a potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation" [8]. Hence, a hazard is understood as some influence that may adversely affect a valued attribute of a system. A hazard is generally but not always external to the system under consideration [8]. Besides, the term "disaster" is what we refer to when a major event hits unprepared population.

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http://dx.doi.org/10.1016/j.ijdrr.2015.05.006
2212-4209/

Alexander makes the point that disaster is usually juxtaposed with resilience: "it is a convulsion in the social system but not necessarily (indeed not usually), a decisive one". Acting on variable scales and leading to different consequences, disasters remain subjective in as much it is "what its victims and participants perceive it to be" [9]. According to the Center for Research on the Epidemiology for Disasters (CRED), an event qualifies as a disaster if at least one of the following criteria is fulfilled: 10 or more fatalities are reported; 100 or more people are reported affected, injured, and/or homeless; the government declares a state of emergency; or the government requests international assistance [10]. Moreover, a disaster is a unique event. Each time one occurs, the ingredients, the controlling parameters and the outcome variables are present in unique mixtures. But disasters are also subject to generalization [9].

In general, governance consists of institutional structures, and is concerned with the ways in which societies can organize themselves to accomplish their goals [11]. The concept of governance can be related to a given socio-ecological system that is potentially exposed to different hazards. By system we mean an organization, such as a coupled human-environment system, a population group, an economic sector, a geographical region, or a natural system. This notion of system was put forward by Füssel as the main component of the assessment framework for the concept of vulnerability [8]. The governance of a system refers to mechanisms by which the agents articulate their interests in order to accomplish their goals (e.g. conservation of natural resources, management of natural hazards). The governance refers also to institutions that influence the exercise of power within the concerned entities (e.g. a firm, a multinational company, a country or a region). Finally, the governance of a system can be described by a participatory interaction among stakeholders at all levels (e.g. the public and private sector, civil society and international organizations) [12].

In particular, environmental governance is the system of institutions, including rules, laws, regulations, policies, social norms, and organizations involved in governing environmental resource use and/or protection. There are a variety of different approaches, one of them, emergent, being adaptive governance [13]. The adaptive governance consists in social structures and processes linking individuals, organizations, agencies and institutions at multiple organizational levels [14,15]. This governance model considers policies and management approaches to be part of a knowledge accumulation process or learning process that results in new approaches that are better able to accommodate uncertainty and surprise [16–18]. Therefore, an adaptive governance approach is put forward as an alternative method of managing complex social-environmental problems including disasters [19,20]. Accordingly, Djalante et al. stated: "Disaster Risk Reduction is a systematic approach to manage disaster risks while adaptive governance is suggested as an alternative approach for governing complex problems such as disasters" [21].

In the field of natural disasters, adaptive governance aims to improve the adaptive capacity of a system by promoting learning processes from the results of management strategies that have already been implemented [16–18,22]. In this respect, the adaptive capacity of a system has emerged from a conceptual distinction between "exploitation", that is, the capacity to benefit from existing forms of collective action, and "exploration", that is, the capacity of governance to nurture learning and experimentation [23,24]. In other words, the improvement of the adaptive capacity of a system seems to be the main objective of an adaptive governance model. The Intergovernmental Panel on Climate Change [1] defines the adaptive capacity as the ability of a system to adjust to climate change, mitigate potential damages, benefit from opportunities, or to cope with consequences. However, components determining adaptive capacity and resilience are not easily separated. This article provides insights into actions that could be taken to improve the adaptive capacity of a system that faces disasters.

A growing number of researchers argue that the adaptive governance can increase resilience to natural hazards. Folke et al. presented adaptive governance as the social contexts necessary to actively manage resilience in social-ecological systems [20]. The concept of resilience has emerged in risk assessment in order to account for the adaptive capacity of urban systems [9,25]. This concept of resilience is increasingly associated with research in vulnerability, and adaptive capacity [26,27]. We understand resilience as the ability of a system potentially exposed to hazards to withstand perturbations or shocks [28,29], by resisting or changing in order to reach and maintain an acceptable level of functioning and structure [30,31]. Djalante et al. highlighted the four characteristics of adaptive governance that are important to help increase resilience to natural hazards [32]. These are polycentric and multilayered institutions, participation and collaboration, self-organization and networks, and learning and innovation. Adger et al. suggested that a multilevel governance system for disaster management enables enhancement of capacity to deal with uncertainties through mobilization of different sources of resilience [33]. Taking the example of the 2004 Indian Ocean tsunami, they argued that the existence of formal and informal institutions as well as large-scale international response helped the affected countries to cope with and recover from the impacts quicker and better, and even permitted the use of the tsunami as a window of opportunity for building long-term community resilience. Based on similar cases, a report by the United Nations Development Program (UNDP) revealed that the Indonesian national platform for disaster risk reduction was formed smoothly due to the existence of a previous analogous entity supported by the recent law 24/2007 on Disaster Management [34].

This article investigates the adaptive capacity and thus the adaptive governance around the Mt. Merapi volcano system. This volcano, located in Central Java, is one of the most active and dangerous composite volcanoes of Indonesia [35] since its eruptions occur every 2–6 years on average over the past 100 years and it is home to 1.4 million people [36,37]. The volcano is located in two provinces (Central Java and Yogyakarta Special Region) and in four districts (Boyolali, Magelang and Klaten districts belong to Central Java Province and Sleman district belongs to Yogyakarta Special Region) (Fig. 1). The focus of our study is the October-November 2010 volcanic eruption of Mt. Merapi whose Volcanic Explosivity Index of 4 (on a scale of 1 to 8) has led researchers to call this eruption the largest ever since 1872 in Java [38]. Data from the National Disaster Management Agency (BNPB, Badan Nasional Penanggulangan Bencana) indicate that after the 2010 Merapi eruption, a total of 367 people were killed and another 277 injured [39]. The evacuation operation led to displacement of almost 400,000 people living within 20 km from the summit for one and a half months [40]. However, after the eruptive phase, another threat endangered local communities: rain-triggered lahars. The Indonesian term "lahar" is used for a mixture of debris and water, other than stream flow, that flows on volcano slopes at relatively high speed [41]. Rain-triggered lahars devastated several villages on the west and south flank of Merapi in 2011 and 2012 [42,43].

The Mt. Merapi case study is of major interest as it broadens our knowledge regarding the adaptive capacity in developing countries that face natural disasters, in particular as the risk management system in Merapi has proven to be successful in previous disasters. The Center for Volcanology and Geological Hazard Mitigation (CVGHM) displayed an updated hazard map for Merapi, as an input for contingency planning that took place in 2009 [41]. However, the rapid onset and large magnitude of the

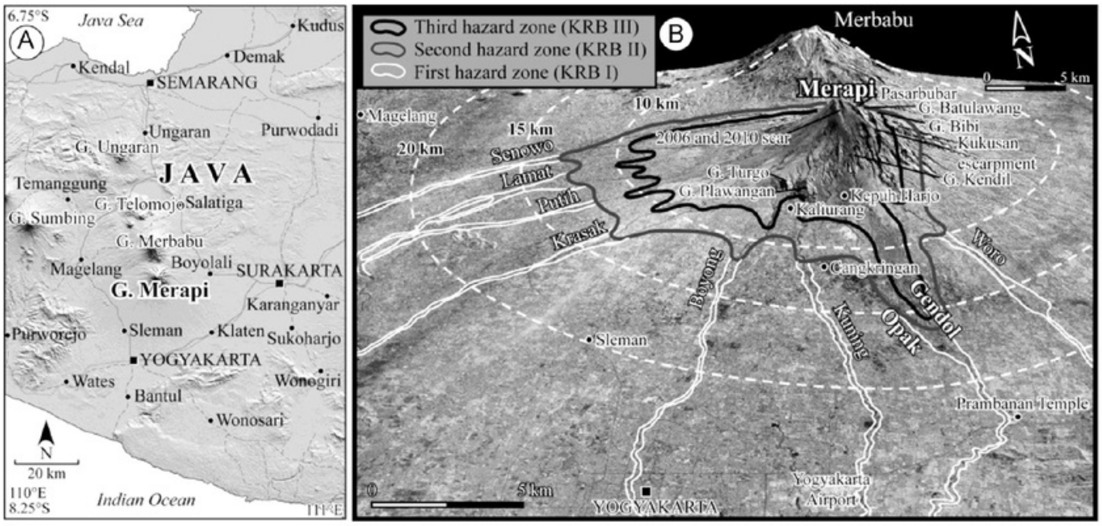


Fig. 1. Location, setting of Merapi volcano in central Java and hazard-zone map [29]. (A) Location of Merapi volcano, the southernmost and youngest volcano of a 165°-trending range of composite cones comprising, from N to S: Ungaran, Telomojo, Merbabu and Merapi volcanoes and surrounding cities. (B) SPOT-5 image of the Merapi-Merbabu area from 10 june 2011, looking NW and draped on an SRTM-DEM. Merapi hazard zones (KRB I–III), as redefined after the 2010 eruption and comprising first, second and third hazard zones are outlined.

2010 eruption of Merapi posed significant challenges for the adaptive capacity of Mt. Merapi. Indonesian researchers and international teams have extensively studied Mt. Merapi volcano, leading to improved understanding of many aspects of the volcanic eruptive processes and aftermath [38]. Recently, Mei et al. [40] studied the evacuation management system of the 2010 eruption of Merapi. But, to our knowledge, none of these studies has explicitly highlighted the governance system that might affect the way in which local communities cope with volcanic eruptions.

The study of governance appears to be a key parameter in the management of large natural disasters. Since the eruption of Mt. Pinatubo in the Philippines in 1992, much experience has been gained to manage large volcanic crises by creating risk zoning maps, improving communications, targeting evacuations and rehousing [44]. These lessons found an application in cases as diverse as the Ubinas eruption in Peru, which lasted three years from 2006 to 2008 and resumed in 2013. In that circumstance, institutions in charge of risk management had to adapt and demonstrate their agility [45]. The creation of hazard zone maps as well as the preparation of contingency plans by local authorities appeared to be a key point. Another interesting case study is the Kelut eruption in Indonesia in 2007, which was sudden. Risk management efforts suffered from an inability of institutions to take decisions while the communication between the population and the authorities failed [46]. These recent case studies need to be complemented by an in-depth analysis of a very large eruption in a densely populated area, in a context where governance is already set up at the time of the crisis. The main question is to understand whether institutions in charge of the risk management exhibit an adaptive capacity to face such challenge.

The methodology of this article consists of literature review and analysis of qualitative data survey. Our field survey is based on face-to-face interviews, conducted from January to April 2011, just following the eruption in the Mt. Merapi area. The collected information was analyzed both manually and by using the text analysis software Tropes®. The software's statistical and linguistic algorithms enable researchers to see connections and relationships in respondents' answers. Such discourse analysis aims at facilitating the understanding of the adaptive capacity of institutions in charge of risk management.

The introduction presents the problem and states the objectives of this study. Section 2 describes the material and the methodology. Section 3 shows the main findings. Section 4 discusses the hypotheses and limitations of the study, and Section 5 highlights the main results.

2. Material and method

Our methodology includes a literature review and analysis of qualitative data survey. We developed a general assessment framework of the adaptive capacity of a system with six interrelated parameters, which complement one another (Table 1). This paper presents a generally applicable assessment framework for the adaptive capacity of a system in the field of disasters that combines six fundamental parameters: context or system description, technology, infrastructure, institutions, information and skills, and economic and financial resources.

Earlier attempts at studying disasters were limited to a specific approach, with a particular focus on environmental, natural and industrial disasters. In this respect, we can cite Füssel [8] who underlined the importance of a system, as the main component of the assessment framework for the concept of vulnerability to climate change. Surono et al. [39] stressed on the technology component of a system and showed that the magnitude of precursory signals (seismicity, ground deformation, gas emissions) were proportional to the large size and intensity of the 2010 Mt. Merapi eruption. Mei et al. [40] highlighted the infrastructure and logistics conditions during the 2010 evacuations at Merapi volcano. Baker and Refsgaard [16] and Chau et al. [47] studied, respectively, the case of the Katrina hurricane and the extreme flood events in Vietnam. They both concluded that large-scale disasters require increased coordination and higher levels of institutional flexibility. Kuhlicke and Steinführer [31] emphasized in their report the role

Table 1
Key parameters for an assessment framework of the adaptive capacity of a system.

Parameters	Explanation
1. System description	Shows whether or not populations are aware of the risk at stake. It comprises the geographical component (locality), the community (region or population group), the hazard, the valued attributes (human life, properties, and agricultural land) and the time scale (short or long-term consequences).
2. Technology	Indicates the technical side of a system. It consists of the implementation and the use of technology while dealing with hazards, such as warning systems, detection instruments, programs, maps and communication tools.
3. Infrastructure	Consists of listing whether or not appropriate infrastructure is available. Such listing may contain improved engineering for buildings, dams, shelters, hospitals, sanitization facilities or roads.
4. Institutions	Detects the existence of formal and informal arrangements. It consists of detecting for what institutions exist on purpose, and for whose interest they exist, persist, or change. Examples of institutions are: land-use planning and management to prevent settlement in dangerous areas, enforcement of building codes and enforcement of property right laws.
5. Information and skills	Indicates the knowledge and the capacity level of a system to face future disasters. A key element is to understand if the likelihood of a disaster, i.e. its precursory event, is sufficient to warrant the mobilization of resources (e.g. the precautionary principle).
6. Economic and financial resources	Indicates whether or not a system is able to hedge possible loss from disaster. Among economic and financial resources, this encompasses: available funds, public saving in cash or livestock, budgetary situation, compensation, and risk sharing through insurance, reinsurance, and other financial products (bonds, actions, credits, and derivatives).

Key: The choice of the six key parameters is influenced by the literature review presented in Section 2. The adaptive capacity of a system is evaluated by assessing both the facilitating and limiting factors for each of the six parameters of the assessment framework.

of information exchange in risk reduction programs. Strömberg [10] highlighted economic losses caused by geophysical and hydro-meteorological events. We assembled all these components into one assessment framework. In our opinion, these parameters describe different facets of the adaptive capacity of a system.

Our holistic interpretation of the adaptive governance system seeks a better reconstitution of a given system. This assessment framework can improve our understanding of the extent of input (e.g. internal and external resources, technological level and knowledge) that a system possesses, while dealing with industrial or natural disasters, etc.

The sequence of the chosen parameters is related to the chronological occurrence of disasters. At the pre-disaster phase, we underline the system description, the use of technology, and the presence of appropriate infrastructures. At the disaster phase, we stress on the existence of solid institutions, and the communication of information. At the post-disaster phase, we highlight the importance of economic and financial resources in order to cover possible loss. Each key parameter highlights a specific side of the adaptive capacity of a system, as potentially exposed to hazards (Table 1). For example, the availability of critical infrastructure or the use of appropriate technology is more likely to promote an adaptive capacity of the system.

Then, we apply our assessment framework to the system focused on volcanic risk management, especially around Mt. Merapi volcano in central Java (Fig. 1). Indonesia has been deeply affected by a range of disasters in recent years, and has a great "potential" for future disasters.

We conducted 18 face-to-face interviews with people in charge of risk management in Indonesia, in February–March 2011, three months after the Mt. Merapi eruption. The main surveys were carried out in the neighbourhood of Mt. Merapi, both in villages affected by the eruption and in the capital of the affected regions (districts of Magelang and Sleman). In order to understand the specificities of the Indonesian system devoted to natural disasters and volcanic risk management, we complemented these surveys with interviews in the neibourhood of Mt. Semeru volcano (regency of Lumajang), another persistently active composite cone located in east Java Island, which shares many characteristics (eruptive activity, hazards, high density of population, etc.) with Mt. Merapi. The combination of the two sites offers an interesting overview of how risk management is perceived and performed in Indonesia, especially in the light of a major eruption widely publicized.

Interviewees were chosen based on the personal experiences of chiefs of villages and planning or rescue staff regarding volcanic risk management and the institutions they depend on. While we could not carry on surveys with the national institutions located in the capital of Indonesia, Jakarta, we were able to survey all relevant institutions at the local scale: districts and sub-districts, municipality, village, and hamlets. The survey comprises 41 questions distributed under six themes (Appendix 1): (1) risk of lahars to which the region is exposed (6 questions), (2) management of lahar risk (3 questions), (3) occurrence of a volcanic or lahar disaster (10 questions), (4) improvement of the financial responses to lahar damages (4 questions), (5) decision making process about lahar risk (5 questions), and (6) preparation and planning for projects (13 questions). We note that collected data were translated from Indonesian and Javanese languages into English.

People in charge of risk management consider volcanic eruption as the most important hazard related to their environment. Their education level ranges from primary school to university. The general profile of our interviewees is presented in Table 2 and Table 3.

We carried out a manual and a computer-based analysis of the content of a questionnaire (Appendix 1). Interviews allowed us a preliminary approach to the adaptive capacity as experienced in the 2010 Merapi crisis. After adding answers to each question in a text file, we used the text analysis software Tropes® (version 8.1). Discourse analysis is particularly pertinent for the analysis of qualitative research [48–50]. The software's statistical and linguistic algorithms clustered and classified the data and identified trends through concept maps or constellations. This generates an

Table 2
General profile of interviewees (gender, age, work status).

	Respondents
Gender	16 males and 2 females
Age	25 to 60 (average 45 years old)
Work status	Positions related to risk management process

Table 3
Detailed profile of interviewees (location and volcano, and task).

Location and volcano	Task
Magelang (city) Mount Merapi	Head of SAR, Magelang
Kaliurang (village) Mount Merapi	Head of SIBAT, Kaliurang
Yogyakarta (city) Mount Merapi	Professor, Head of PSBA
Srumbung (village) Mount Merapi	Chief of Srumbung village
Blongkeng (village) Mount Merapi	Secretary of Blongkeng village and shelter management
Agomulyo (village) Mount Merapi	Head of social and management section in Agomulyo village
Bronggang (hamlet) Mount Merapi	Chief of Bronggang hamlet
Kaliurang (village) Mount Merapi	Retired
Mt. Sawur *Mount Semeru*	Staff on Mt. Sawur observatory
Lumajang (city) *Mount Semeru*	Control for improvement and expansion
Lumajang (city) *Mount Semeru*	Engineer
Lumajang (city) *Mount Semeru*	SAR Trainer
Candipuro (village) *Mount Semeru*	Planning Staff
Pasrujambe (village) *Mount Semeru*	Flood information official on Besuksat River, member of rescue team
Pasrujambe (village) *Mount Semeru*	Staff in Pasrujambe Sub-District
Pasrujambe (village) *Mount Semeru*	Chief of Pasrujambe village
Kamituwo (hamlet) *Mount Semeru*	Chief of Kamituwo hamlet
Pronojiwo (village) *Mount Semeru*	Entrepreneur

Abbreviations and acronyms:
SAR: National Search and Rescue Agency.
PSBA UGM: Research Center for Disasters, Gadjah Mada University, Yogyakarta.
Key: As shown in the table, our interviewees have gained experience in disaster management on the slopes of Mt. Semeru and Mt. Merapi, two volcanoes subject to frequent eruptions whose slopes are regurlay affected by lahars and mudflows.

accurate word count of references, verbs, adjectives and substantives that would be difficult to achieve using the constant comparative method. The software's algorithms also generate linguistic analyses of the style of the text and connection of concepts for every corpus we analyse. The term "reference" designates one or more words sharing the same root and having similar meanings. Moreover, the software allows a graphic presentation of the relationships of words to a chosen reference.

The area graph (Fig. 2) shows the relationships between the reference "catastrophe", one of the most used sentences in our surveys, and other references. In this area graph, each reference appears as a sphere, whose surface is proportional to the number of words it contains. The central reference is "catastrophe". The references on the left are its predecessors, those on the right its successors in the text of our interviewees. The distance between the central class and other classes is proportional to the number of relationships connecting them.

Accordingly, we note that the two classes "catastrophe" and "communication" are close together, which implies that they share many relationships. Moreover, in the discourse, "communication" and "social groups" are mentioned before the catastrophe, which reflects the importance of collective prevention before a disaster occurs. After a catastrophe, the surveyed people are first aware of population's health. Then, they consider the main problems of river conditions (waterway), communications, food, housing and security. Questions related to law and to business appear to be secondary compared to these fundamental issues.

3. Results

This section will expand our knowledge of the communication linkages around Mt. Merapi, the chronological phases of volcanic eruptions and actions taken around the volcano, and the adaptive

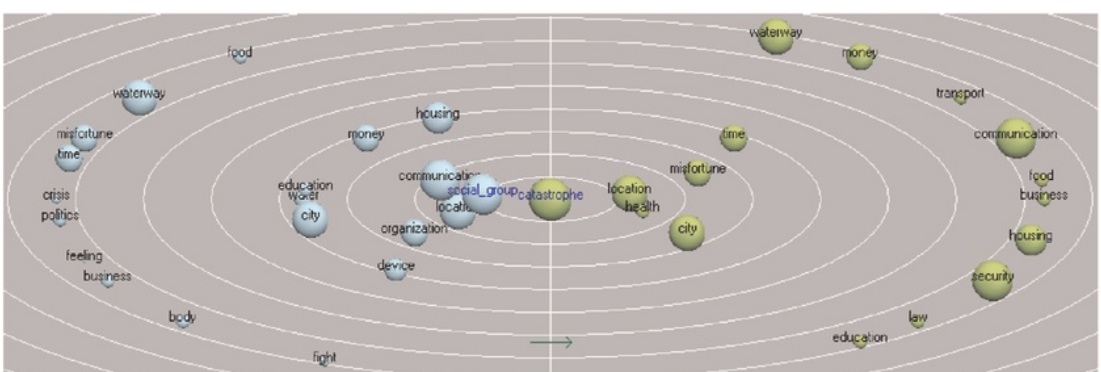


Fig. 2. Connections between the reference "Catastrophe" and other references. Our data set was processed using Tropes.

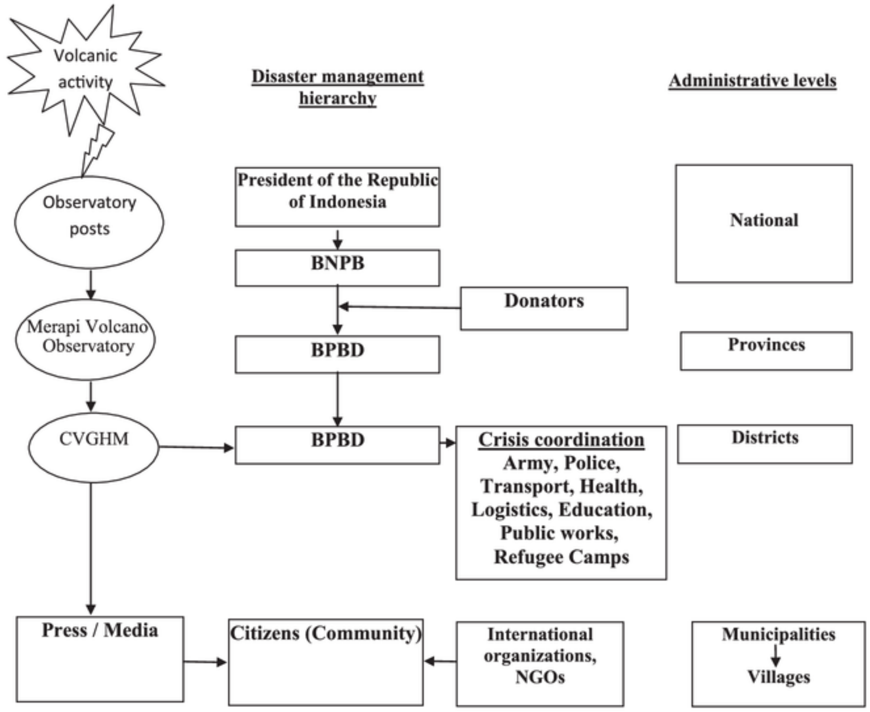


Fig. 3. Flow diagram of the administrative levels and the communication chains in the area of Mt. Merapi. BNPB: Badan Penanggulangan Bencana (National Disaster Management Agency). BPBD: Badan Penanggulangan Bencana Daerah (Regional Disaster Management Agency). CVGHM: Center for Volcanology and Geological Hazard Mitigation.

capacity in Mt. Merapi system.

3.1. Communication linkages around Mt. Merapi

The Law of the Republic of Indonesia, no. 24/2007 defines objectives of risk mitigation, roles and responsibilities of government and stakeholders, as well as funding sources for disaster management [51]. According to this law the entire management system is placed under the supervision of the President of the Republic in order to manage all types of natural and man made disasters. Furthermore, the power and legitimacy to act is given to the National Board for Disaster Management (BNPB), which was established by the same law. BNPB is represented by local agencies named BPDB (Local Disaster Management Agency) and located at different institutional scales (Province and District). The BNPB does not work individually, but in cooperation with various departments, agencies and institutions. For example, in search and rescue of victims of disasters, BNPB collaborates with the National Army, the National Police, Basarnas (Indonesian Search and Rescue) and PMI (Indonesian Red Cross). To manage displaced persons, the BNPB cooperates with the Ministry of Social Affairs. For mapping areas at risk, the BNPB works with BIG (National Bureau of Spatial Information) and departments and agencies to deal with special risk. In the warning system organization in case of disaster, the BNPB works with the Ministry of Energy and Mineral Resources and BMKG (Meteorological, Climatology and Geophysics Agency) for geological risks, the Ministry of Public Works, the Ministry of Agriculture, the Ministry of Forestry, LAPAN (National Space Agency) for hydro-meteorological hazards, supported by studies conducted by the Ministry of Research and Technology, LIPI (institute of Science) and universities across Indonesia. For disaster risk reduction education purposes, the BNPB works also with the Ministry of National Education, Ministry of Religious Affairs and the Ministry of Communication and Media [52]. The mechanism of distribution of donations is based on the Regulations of Chief BNPB no.7 2008. Aid from donors is delivered to the Internally Displaced Persons (IDP) camps, under the coordination of BNPB and BPBD.

The flow diagram of management system and communication linkages, emphasizing connections between scientists, government administrations, private organizations, and the public is presented in Fig. 3. The administrative levels in Indonesia are as follows: national, province, district, sub-district, municipality, and village. A municipality encompasses several villages. In order to monitor volcanic activity, five observatory posts have been installed around the Merapi volcano since 1950–1970s. Information about the eruptive condition and the behaviour of the volcano is reported from each of the observatory posts to CVGHM's Volcano Investigation and Technology Development Office (BPPTK) and to the Merapi Volcano Observatory (MVO, a section of BPPTK) in Yogyakarta and then transmitted to CVGHM. The information on volcanic activity is regularly reported to local governments (i.e. the head of district). The BPBD is the coordinator of crisis management. Thus, the head of district together with BPBD coordinates each department involved in the crisis management. At the local scale, the chiefs of villages together with the chiefs of sub-villages and local organizations, and with the help of army, police, NGOs and volunteers prepare the emergency and evacuation plan. However, if the danger is imminent, the BPPTK can use sirens to inform people directly to evacuate. The volcanic crisis management is organized in each of the districts and is based on the

Table 4
Chronological events of volcanic activity, actions taken, and loss.
Source: this survey, [39,40,52].

	Warning level*-Radius of danger zone (KRB)	Volcanic activity	Actions taken	Loss, IDPSs**, and problems faced
1. Pre-eruption stage (20 september–25 october 2010)				
Sep. 20th	II–10 km	Dramatic increase in all monitored parameters	CVGHM***: need to evacuate tens of thousands of people. Release of information related to preparation for evacuation. 1. Maximal level of the warning system. 2. Local authorities: evacuation of persons with special access and functional needs, the elderly, children and pregnant women, for the villagers living in KRB III. 3. CVGHM: warning that there was a high probability of an unprecedented explosive eruption.	1. No human and material loss. 2. Mbah Marijan, the "gatekeeper of Merapi" refused to leave his house in Kinahrejo. 3. Some refusals to evacuate despite orders.
Oct. 21th	III–10 km			
Oct. 25th	IV–10 km			
2. Initial explosion (26 october–02 november 2010)				
Oct. 26th	IV–10 km	1. First explosive eruption. 2. Production of a 12 km-high ash plume and PDCs*****.	1. CVGHM: order to evacuate 12 municipalities (total of 24,024 habitants) located in the KRB III. 2. Local authorities: order to evacuate people in the danger zone. 3. BPPTK****: release of monitoring and recommendations data every six hours.	1. 35 people (Marijan and 34 others) died. 2. 22,599 IDPSs.
Oct. 30th	IV–10 km		Army, Police and rescue teams: evacuation of the dead and injured, and searching for missing people.	53,048 IDPSs.
3. Increased eruption intensity (03–04 november 2010)				
Nov. 3 rd	IV–15 km		CVGHM: recommendation to evacuate 32 municipalities (total of 90,325 habitants) located in the KRB III.	76,031 IDPSs.
Nov. 4th	IV–15 km	Paroxysmal eruption took place.	CVGHM: extent of the danger zone to 20 km from the summit and call for evacuation.	1. 82,701 IDPSs. 2. No refugee camps beyond 20 km to accommodate the IDPs. 3. Evacuations were taking place spontaneously.
4. Sustained explosive eruptions (05–13 november 2010)				
Nov. 5th	IV–20 km	1. Paroxysmal eruptions for 24 continuous hours. 2. Ash fell in the region west and south of the vent. 3. PDCs reached 16 km from the summit in the Gendol River.	Local authorities of the Sleman district: preparation of a new IDP camp in Maguwoharjo football stadium (located 23 km from Merapi).	1. About 200 people died. 2. 239,618 IDPSs. 3. CVGHM did not communicate the list of villages to be evacuated. 4. Misunderstanding by some of the emergency managers. 5. All IDP camps were located inside the restricted zone.
Nov. 8th	IV	Volcanic activity started to decrease in intensity.	Most of the IDP camps utilized after the main explosion were public buildings (schools, hospitals, stadiums, village halls, and universities) or even residents' houses or yards.	Local authorities faced logistical difficulties (e.g. recording IDPs, distributing aid and assistance).
Nov. 13th	IV	Decrease in the explosive activity of the volcano.		381,696 IDPSs.
5. Decreased volcanic activity (14–19 November 2010)				
Nov. 14th	IV 20–15–10 km	Decrease of the explosive activity of the volcano.	CVGHM: recommended decreasing the radius of the danger zone as follows: maintaining a radius of 20 km for the sector between the Boyong and Gendol rivers (mainly within Sleman District), but reducing the radius to 15 km for Magelang District and to 10 km for Klaten and Boyolali Districts.	1. 399,403 IDPSs, reaching a peak level. 2. 464,328 habitants in the restricted area.
Nov. 19th	IV			1. 272,124 IDPSs. 2. Many IDPSs were closed 3. Concentration in one central camp in Maguwoharjo.

Table 4 (*continued*)

	Warning level*-Radius of danger zone (KRB)	Volcanic activity	Actions taken	Loss, IDPSs**, and problems faced
6. Post-eruption stage (20 November–9 December 2010)				
Nov. 20th	IV–15–10–5 km	Decrease of the explosive activity of the volcano.	CVGHM: recommended decreasing the radius of the danger zone as follows: 15 km for the sector between Boyong and Gendol rivers, 10 km for the rest of Sleman District, Magelang and Klaten Districts, and 5 km for Boyolali District.	190,902 habitants in the restricted area.
Dec. 3 rd	III–10 km			51,924 IDPSs.
Dec. 9th	III–10 km			< 20,000 IDPSs.

Key: The 2010 Mt. Merapi eruption can be divided into six chronological stages. The explosive activity of the volcano has led to a wide range of actions and recommendations starting from September 20th to December 9th 2010. On November 5th 2010, sustained eruptions occurred, exerting a death toll to nearly 200 people. This stage was characterized by an absence of coordination between CVGHM and other emergency planners. Besides, the number of displaced people increased dramatically over time and reached its peak on November 14th with 399,403 IDPSs.

* Four warning levels, from I to IV, define volcanic activity as follows: "normally active, on guard, prepared, and beware conditions".
** Internally Displaced Persons.
*** Center for Volcanology and Geological Hazard Mitigation.
***** Pyroclastic density currents
**** Merapi Volcano Observatory.

recommendations of the CVGHM [40].

3.2. Chronological phases of volcanic eruptions and actions taken at Mt. Merapi

The review of the chronology of volcanic activity in 2010 and actions taken has enabled us to better understand how the Mt. Merapi system reacted to disasters. The 2010 Merapi eruption began on the 26 of October. In response to the increasing volcanic activity, a number of strategic actions had been taken (e.g. warning and evacuation). At the pre-eruption and the initial eruption stages (from 20 September to 2 October 2010), the actions taken by the CVHM met the population expectations and needs. However, as the eruption lasted about three weeks, the lack of preparedness and readiness for coping with the volcanic activity put into question the adaptive capacity of Mt. Merapi system. The increased eruption intensity led to hundreds of fatalities (inhabitants who refused to evacuate or returned to their villages during the eruption) and to numerous logistics problems (e.g. spontaneous evacuation, insufficient shelters, poorly organised aid distribution).

Overall, we distinguish six chronological stages of the 2010 Mt. Merapi eruption [39,40,52]. These stages are chained in Table 4 with respect to the changes observed in volcanic activity and the undertaken actions. Besides, every explosive eruption of Mt. Merapi volcano is usually followed by frequent rain-triggered lahars in the rainy season, which occur weeks to months after an eruption (between October and May). Triggered lahars reflect the long-term impacts of explosive eruptions. Over 240 rain-triggered lahars were recorded during the 2010–2011 rainy season between October 2010 and May 2011, and 42 at the beginning of the 2011–2012 rainy season between October 2011 and January 2012 [39,42]. Lahars generated avulsions (sudden overbank and shift of the river channel towards another non-flooded channel) on the distal slopes of Merapi volcano, potentially creating major disasters in densely populated areas [42,43].

3.3. Adaptive capacity of the Mt. Merapi system

Given the 2010 disaster's magnitude (VEI of 4, volume of 70 million m3 of pyroclastic debris, 367 fatalities and 399,403 internally displaced persons), actors of the disaster management hierarchy (Fig. 3) had to deal with a critical situation. Their decisions contributed to mitigate the impact of the disaster (e.g. evacuation operations, information dissemination, and aid distribution). Moreover, the total of 367 fatalities is relatively small compared to the number of people (10,000 to 20,000 people) who might have died without the evacuations [39]. Given this situation, this section aims at measuring the adaptive capacity in Mt. Merapi system. As noted earlier, the assessment of the adaptive capacity of a system depends on six interrelated parameters. We will measure the role of these parameters, as experienced by our interviewees and noticed in the field. Fig. 4 presents various aspects of our fieldwork after the eruption.

3.3.1. System description

The analysis of our respondents' answers highlights the critical context in which communities operate (Table 5). All respondents confirmed that they have already witnessed a volcanic eruption and a mudflow directly in Indonesia, mostly in 2010 and 2011. The village appears to be the main relevant unit for risk management, even if decisions are taken at an upper level. Information is thus provided directly at the local scale to all people concerned by the volcano. Such proximity is the best way to communicate information that may be acknowledged by local people.

The slopes of Mt Merapi in February 2011. At the foreground, destructions by pyroclastic surges and lahars. At the background, remaining inhabitants (here: Gendol River).

An example of broken dam on the slopes of Mt Merapi. Many facilities against floods and lahars were destroyed following the eruption (here: Woro River).

People who lost their home were given the opportunity to live in shelters established close to their ancient village but outside river channels (here: Cangkringan village).

The volcano is a source of benefits for many people who extract building material from flooded valleys (here: Magelang village).

An example of survey performed within risk management institutions (here: SIBAT, Kaliurang village).

The eruption emphasized the key role of observatories in risk prevention (here: Kaliurang).

Fig. 4. Various aspects of our fieldwork after the eruption of Mt Merapi (pictures: G. Enjolras).

3.3.2. *Technology*

Monitoring and warning systems have been set up in all rivers that drain the flanks of the Mt. Merapi volcano. The early warning system around Mt. Merapi is based on the analysis of instrumental and visual observations for a better accuracy. These two kinds of analyses are complementary because the onset of an eruption can be forecasted using seismographs while the sudden outbreak of a lahar can only be perceived in the field.

For the majority of our respondents (94%), risk assessment relies on identified indicators, such as rainfall intensity and duration (which leads to an increase in river water level) and delivered information by local residents to the public. These indicators allow them to identify the intensity and the likelihood of the expected hazard. However, they may be subjective or based on rudimentary instruments. A respondent stated that flood might occur "whenever the rain falls heavily". Another respondent added, "As an indicator, there is a water level gauge, measured in high and low river stage, using a light bulb. If the bulb is broken, it means that the water is high". Indeed, a monitoring system existed before the eruption but was severely damaged. During the weeks that immediately followed the eruption, the system was updated and resized to facilitate observations of the volcano and the valleys while improving radio communications. Further, the implication of local youth (supervised by people from NGOs, universities and volcanologists) in lahars risk monitoring and disaster risk reduction becomes important since the awareness of lahars' hazard

Table 5
The most recurrent "References", "Verbs" and "Adjectives" in the themes "Early warning and risk monitoring", as generated by Tropes. Numbers in brackets indicate the number of occurrences.

References	1. Crises: Lahar (60), River (25), Calamity (22), Alarm (20), Volcano (19). 2. Dates: 2010 (10), 2011 (9). 3. Locations: Village (17), Merapi (14), Area (10). 4. Communication & Medias: Information (14), Guard (8), Instruction (4). 5. Social Groups: People (12), Leader (11), Refugee (7) and Inhabitant (5).
Verbs	1. Verbs of state: to Be (50), to Know (5), to Happen (4). 2. Verbs of action: to Face (18), to Evacuate (8), to Announce (6).
Adjectives	1. Local (7), Warning (5), Dangerous (4), Public (4), Urgent (5).

Key: The table reflects the dangerous context in which communities operate, although they are aware of the risk of volcanic eruption. One respondent stated: "People live very close to the lahar. With limited funds, people do not want to move from there". The early warning system around Mt. Merapi is based on the analysis of instrumental and visual observations.

Table 6
The most recurrent "References", "Verbs" and "Adjectives" in the themes "Improvement projects", as generated by Tropes. Numbers in brackets indicate the number of occurrences.

References	1. Locations: Villages (36), District (5), Location (3). 2. Crisis: Calamity (9), Victim (8), Emergency (4), Risk (3). 3. Health, Life & Casualties: House (16), Health (3). 4. Business & Industry: Benefit (10), Cost (5), Economy (3), Electricity (3).
Verbs	1. Verbs of state: to Be (47), to Have (11). 2. Verbs of action: to Build (5), to Support (5).
Adjectives	1. Temporary (19), Public (6), Local (3), Urgent (3).

Key: Local inhabitants consider project impact as positive because they feel safer and more motivated to work during their temporary stay in shelters. Our respondents underline the improvement of the economic and sanitation conditions (electricity, water).

increases. Local youth helped evacuate residents (especially children, women and elderly people) and kept them away from the flood plain of the rivers.

3.3.3. Infrastructure

Infrastructure facilities (e.g. dams, bridges, public bathing and shelters) are not adequate to cope with large-scale disasters. In the aftermath of the 2010 volcanic eruption, a large number of bridges and roads were destroyed, isolating many villages. For the first time, Merapi eruptions resulted in major disruptions of air traffic in Yogyakarta (2463 flights were cancelled [40]).

In order to improve this relatively poor infrastructure, a number of projects have been conducted, especially in 2011. The respondents included in our survey provided information regarding seven projects (Table 6) that aim to improve the capacity to cope with future crisis, such as building temporary shelters, evacuating villages, providing clean water, mapping, and determining evacuation routes. Improvement projects are mostly co-financed by national organizations, and NGOs, such as the Government, the Indonesian Red Cross, the Denmark Red Cross, the Japanese government and private organizations.

People and infrastructure at stake are mostly located in some villages located on the slopes of Mt Merapi, but also in valleys that start on the flanks of the volcano. Because the most affected people usually do not want to move outside their village after the crisis, improvement projects have to be designed close to affected areas but in safe locations. At the time of the surveys, most of these projects were conceived as temporary. The lack of funds has led transitory choices to become perennial decisions. After the 2010 Merapi eruption and lahars, we distinguish between temporary housing (hunian sementara) and permanent housing (hunian tetap) that differ in their locations and construction materials.

3.3.4. Institutions

Co-ordination among institutions is mainly oriented towards relief operations (e.g. information dissemination, financial compensation) and repairing damage (e.g. building shelters) resulting from volcanic eruptions and rain-triggered lahars. The respondents mentioned a number of institutions that we divided into three categories of institutions (Table 7): Local Government (LG), Civil Society Organizations (CSO) and Community Representatives (CR). They underline the presence of International institutions and NGOs, e.g. the Indonesian Red Cross.

The respondents included in our survey believe that Local Government (LG) and Community Representatives (CR) are the most important institutions since they are linked to major administrative institutions (e.g. Central Government) and have the legitimacy to act. In addition, some of the respondents consider that the Indonesian Red Cross is the most important institution as it maintains partnerships with other international institutions such as the Danish Red Cross. However, others chose Civil Society Organizations (CSO) over LG or CR because they have no bureaucracy constraints and can provide quick support (money, food) to local inhabitants.

According to the respondents, the institutions that should first react when lahars occur are: neighbors, local authorities (village chief, rescue team, personalities), and Sub-District authorities. This

Table 7
Three categories of institutions are acting around Mt. Merapi. Numbers in brackets indicate the number of occurrences.

Institutions	Examples
1. Local Governments (LG)	District and Sub-district, municipality, village, police and army, department of public works, department of health.
2. Civil Society Organizations (CSO)	Rescue team, private companies.
3. Community Representatives (CR)	Village chief.

Key: There is a strong coordination among institutions in Mt. Merapi with a growing involvement of NGOs and private organizations.

Table 8
Means and localities used for the dissemination of information, as generated by Tropes software. Numbers in brackets indicate the number of occurrences.

Dissemination of information	Examples
Means	Public meetings (17), Radio (15), Television (14), Evacuation simulation (13), Press (12), Posters (11).
Localities	Public places (15), Mosques (12), Schools, Work places, Police stations (12), Houses (11), Health centers (9) and Associations (sport, politics) (5).

Key: A wide range of communication supports is used to inform people in all relevant places where they spend time (e.g. home, schools, public administrations, worship spaces).

indicates a participatory approach that is facilitated by strong social networks and bottom-up relationships. However, a number of limitations persist. The hierarchical system of the Indonesian disaster management (Fig. 3) may lead to bureaucracy, which does not favour an early response and may facilitate corruption. Moreover, our respondents asserted that most of constructions are set up illegally and without property rights in areas reported to be dangerous according to contingency plans. Such situation generated conflicts for the compensation and relocation of victims.

3.3.5. Information and skills

The dissemination of information among institutions and population is provided by a wide variety of means, persons and localities (Table 8). During the emergency response period in 2010, orders to evacuate were permanently communicated through a variety of direct communication channels (e.g. public meetings, radio and TV announcements) and as a result many thousands of lives could be saved.

Information and skills around Mt. Merapi are generated by a beneficial co-operation between scientists and communities by using reliable scenarios and instruments (e.g. social networks, radio, mobile phones). This self-organization facilitates the dissemination of warnings among people living in hazard-prone areas before the arrival of a lahar. Hence, maps and evacuation plans are regularly updated and posted in villages. As a result, the majority of the respondents (89%) believe in the correctness of the delivered information. However, our respondents mentioned a number of limitations, such as imprecise documentation for both human and material loss, and incompleteness of the delivered information. It implies that the authorities give the priority to the study of volcanic hazards compared to the study of vulnerability, which is more complex.

3.3.6. Economic and financial resources

Financial resources are a key component for the management of a volcanic crisis. They are needed before an eruption for prevention purposes (education, dams, roads, signs), during an event for emergencies (evacuation, relocation, first aid) and after for recovery (compensation, rehabilitation, improvement projects). However, the lack of economic and financial resources appears to be a weakness for the adaptive capacity at Mt. Merapi.

In the Indonesian system, financial resources devoted to natural disasters are allocated on a case-to-case basis before and after a disaster [51]. Because resources are not perennial, local institutions have to ask for support from private companies (TV channels) or foreign institutions (NGOs). When a large disaster occurs, the government applies a compensation process that is channeled with a top-down approach as follows: the District, the Sub-District, and the village, then to the victims. Due to bureaucratic constraints, all necessary funds do not arrive in a timely fashion

Table 9
The assessment framework of the adaptive capacity around Mt. Merapi volcano.

Key parameters	Facilitating factors to an adaptive capacity of Mt. Merapi system	Limiting factors to an adaptive capacity of Mt. Merapi system
System description	1. Well-defined system. 2. Perception of volcanic eruption as a potential risk.	1. Complex interactions across institutions of different scales (e.g. local institutions). 2. Eruptions and lahars pose complex, uncertain and ambiguous risks.
Technology	1. Monitoring and warning systems exist in all rivers that drain the Merapi volcano. 2. Mapping using GPS. 3. Community awareness of "disaster management" devices/technology.	1. Electric shortage. 2. Seismograph out of order. 3. Lack of advanced technology. 4. Many early warning devices were stolen and/or vandalized.
Infrastructure	1. Infrastructural projects have been conducted (e.g. build temporary shelters, provide clean water and determine evacuation routes).	1. Lack of adequate infrastructure (e.g. dams, bridges, soil protection, roads, river excavators, public bathing, shelters).
Institutions	1. Presence of International institutions (e.g. Indonesian Red Cross). 2. Co-ordination among institutions especially when disasters occur. 3. CSO provide quick support to local inhabitants. 4. Co-ordination among institutions for the dissemination of information. 5. Training of disaster management units (national and local levels). 6. Social networks among the population. 7. Community-based disaster and crisis management	1. Presence of bureaucracy in LG. 2. Lack of respect for law enforcement. 3. Limitation of CSO to projects and short-term activities. 4. Co-ordination efforts among institutions are only oriented towards relief (emergency management). 5. Time wasting in coordinating different institutions. 6. Absence of continuous contact between institutions. 7. Population relies on informal local networks (neighbors) for rescue.
Information and skills	1. Information dissemination with a variety of means and localities. 2. Preparation of evacuation maps and emergency simulations. 3. Education for disaster management.	1. Lack of public awareness in reacting to emergency simulations. 2. Unprecise quantitative documentation. 3. Emergency plan depends to a large extent on CSO and CR.
Economic and financial resources	1. Financial compensation provided by a wide range of institutions (including social capital/local community funds/reserves in case of disaster). 2. Financial compensation can take different forms such as food, clothes.	1. Time wasting in delivering the compensation. 2. Dependence on funds from external parties. 3. Absence of sophisticated financial coverage such as catastrophe bonds. 4. Limited commercial, industrial and agricultural activities.

Key: This table evaluates the adaptive capacity around Mt. Merapi. Although a number of actions (e.g. evacuation simulations, co-ordination efforts between institutions) have been undertaken, a number of limitations persist (e.g. lack of facilities, poor infrastructure).

and villages have to rely on solidarity, which is material such as food and clothes. However, for the villages located near to the Merapi summit, many villagers have livestock as saving that they sell during crisis periods. They also have public saving either in cash or livestock [52].

The system could be improved with the generalization of basic mechanisms such as reserve and solidarity funds at the local and national scales. These two solutions are the most cited by the respondents (respectively 46% and 29%). In a developing country, blocking funds for an uncertain use may not be easily understood, but Indonesia faces many eruptions each year at the national scale. Insurance policies are not considered as a reliable way to hedge risk because of the amount of premiums compared to the standard of living and the cultural change they represent [53]. At the moment, only a micro-insurance scheme devoted to flood risk is available in some parts of Indonesia [54]. Besides, a large number of the respondents (59%) cannot formulate any estimate of the human loss that an eruption or a lahar can cause. In order to estimate the amount of material and human loss, inhabitants refer to maps, which indicate the number of houses located near the river.

4. Discussion

Our analysis has revealed challenges that a major disaster such as a rapid and larger-than-expected eruption may pose and solutions needed to improve the capacity of a system to cope with future crises. Lessons learned at Mt. Merapi after the 2010 eruption may be useful to improve the ability of risk management institutions to deal with volcanic eruptions and other disasters. Based on this analysis, Table 9 summarizes the facilitating and limiting factors to an "improved" or "more efficient" adaptive capacity of a system.

Table 9 highlights different ways by which the adaptive capacity, and thus the adaptive governance, of a system can be improved. For effective response in the future, it is necessary to work further with communities to develop strategies that they will accept and comply with. Several steps can be taken in the future to improve future evacuations, such as: (1) a more complete integration of disaster risk reduction education into school curriculum, (2) a development of an updated disaster database which includes loss, (3) a better and maintained facilities (roads, IDP camps, etc.), (4) a more effective dissemination of accurate information, and (5) an elaboration of multiple hazard scenarios for contingency not only for pyroclastic density currents (PDCs) but also for lahars at local scale (desa/dusun).

Besides, inhabitants living on and around Mt. Merapi are likely to have adapted in various ways to their hazardous environment. Interpretations of risks are shaped by their own experience, personal feelings and values, cultural beliefs and interpersonal and societal dynamics [55]. The available choices in everyday-life are perceived to present greater threats to survival than the threat posed by natural hazards. The need for securing daily livelihoods prevails over volcanic risk perception while religious beliefs enable people to cope with the threat by providing alternative explanations at the time of a disaster [56]. Furthermore, lahars produced by rains on the Merapi volcano bring a valuable resource to communities of villagers, who are ready to increase their exposure to hazard by quarrying deposits in valleys filled by lahar deposits.

However, results provided in this study may be very context-dependent. Our sample of 18 face-to-face interviews with key actors of the management of volcanic crisis, especially the 2010 Merapi eruption, does not pretend to be representative of the population living around Mt. Merapi. Despite these limitations, our results stay in line with other studies undertaken on the eruption and its management. According to Mei et al. [40], the 2010 Merapi volcano eruption provided another example of a successful evacuation. Such a rapid evacuation and displacement of hundreds of thousands of people had not been tested before in a highly hazardous explosive eruption [57]. An efficient community-based hazard management prevented significant human loss [42].

5. Conclusion

This study has examined the adaptive capacity and the adaptive governance of a system. We have developed and applied an assessment framework of the adaptive capacity of a system, potentially exposed to disasters using six complementary criterias. The case study focused on Merapi in the densely populated island of Java, Indonesia, which can be considered as an example of adaptive governance facing the frequency of explosive eruptions of this volcano. The 2010 Merapi eruption was much larger and longer than anticipated by contingency planners. Before the 2010 eruption, the contingency plan for each district (kabupaten) was only limited on PDC scenario. The choice of this case study seems to be relevant because the 2010 Merapi eruption has caused various consequences, including environmental degradation, loss of life and property. We were able to carry out surveys with the main actors of the Merapi rescue system only three months after this major event.

(1) During the crisis, confusion and disruptions of networks and infrastructures revealed the need to prepare for larger-than-normal eruptions. Our results showed that preparation before the eruption was critical to the management of the eruption because lives could be saved and people at risk could be relocated. The adaptive capacity of Merapi system could be evaluated as quiet acceptable. However, rating an adaptive governance system as successful is not only based on the number of lives saved, but also on the way actors behave and their reaction during the crisis (evacuation, transportation, first aid, relocation, etc.).
(2) Enhancement of the adaptive capacity factors may improve the Merapi governance system in order to deal with future eruptions. In particular, a greater emphasis should be made on the evaluation of overall vulnerability around the volcano, leading to a rapid enlargement of the restricted zone, and on the development of a financial system able to cope more efficiently with disasters.
(3) The theoretical aspect of our research leads to a deep understanding of the concept of adaptive governance. In applying the adaptive capacity assessment framework to the aftermath of the 2010 Merapi eruption, this article combines both theoretical and practical aspects.
(4) This work represents a contribution to interdisciplinary research for the management of natural and man made disasters (e.g. environmental and industrial disasters). The assessment framework of the adaptive capacity, however, is applicable to any system of equal complexity. Government, policy makers, and other stakeholders may use this approach in developing and assessing critical reforms in the decision-making process.

Acknowledgements

This study was undertaken with the support of the French National Research Agency (ANR) under the framework of the project "Laharisk". We thank Alix Hague for the English editing.

Appendix 1. Questionnaire used for the surveys

Semi-structured interview / Questionnaire on lahar risk management

Identification of the respondent

Name / Surname	
Age	
Sex	
Adress	
Telephone	
Email	
Institution	
Task	
Years of incumbent	
Education	Primary School General School Senior High School University Non educated

Within the framework of this survey, we are interested in the risks and we are particularly focusing on natural risks, that is to say the risks relative to our environment

Q1. Order these hazards related to our environment from the most important to the least important (From 1 to 5, 1 = most important; 5 = less important)

… **Volcanic eruption**

… **Lahar or mud flow**

… **Seismic risk**

… **Tsunami**

… **Other** ___________________________________

With respect to the risks of lahars, to which the region is exposed

Q2. Are you aware of lahar risk on Merapi volcano?

- ❑ **Yes**
- ❑ **No**

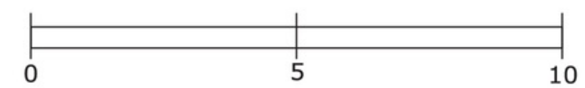
Q3. Have you already witnessed a lahar directly?

- ❑ **Yes**
- ❑ **No**

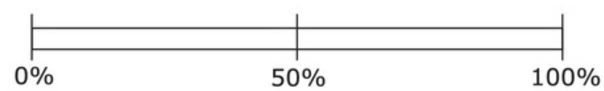
If your answer is positive, did you observe a change in your professional behavior?

Q4. How often have you faced risky situation generated by lahars?

Q5. On this scale, please indicate the risk level a lahar represents for the population (life, house, job…)? (0 = no threat; 10 = great threat).



Q6. On this scale, please indicate the probability of occurrence of a destructive lahar in the next two years.



Q7. On this scale, please indicate the probability of occurrence of a destructive lahar in the next five years.

Regarding the management of lahar risks…

Q8. If a lahar is coming, which institution should first react? (Please choose a single answer)

- ❑ The neighbors
- ❑ The local authorities (Rt, Rw, village chief, rescue team, personalities)
- ❑ The sub-district authorities
- ❑ The regency
- ❑ PBPPTK

Q9. According to you, which decisions should be taken in order to mitigate risks and to reduce the loss (human and material) generated by lahars?

Q9a. Administrative solutions

	Little	Much	Not at all
Signs in dangerous areas			
(More) precise zoning of risky areas			
Preserved zone near the volcano (no construction, natural park)			
Legislation that prevent the population continuing building and living along the rivers			
National legislation for the education and the protection of the population			
Other			

Q9b. Technical solutions

	Little	Much	Not at all
Evacuation roads			
Retaining walls			
Dams (sabo…)			
Floodway			
Other			

Q9c. Humanitarian solutions

	Little	Much	Not at all
Compulsory purchase			
Emergency evacuation			
Population transfer			
Other			

Q9d. Preventive solutions

	Little	Much	Not at all
Educative projects (population, students, teachers)			
Evacuation simulation			
Mass media information			
Other			

Q9e. Financial solutions

	Little	Much	Not at all
Individual savings			
Solidarity fund			
Compensation of loss by the regency			
Intervention of the Indonesian State			
International help and support			
Other			

Q10. Do you have indicators that allow to measure and to evaluate the effectiveness of the policies against catastrophes?

- ❑ **Yes**
- ❑ **No**

If your answer is positive, can you describe them?

If a disaster occurs (volcanic or lahar crisis)

Q11. Does a monitoring and warning system exist on all rivers that come from Merapi volcano?

- ❑ **Yes**
- ❑ **No**

Q12. Who gives the alert? Is it frequent?

Q13. Do you have an emergency plan that should be followed when necessary?

- ❑ **Yes**
- ❑ **No**

Related to the risk management in case of lahars

Q14. Can you describe next the stages of this plan and how it would be carried out in case of emergency? (From the implementation of the plan to the protection of the population) How is it implemented in terms of spatial organization, priorities?

Q15. Do you have an idea of the human loss than a lahar can cause depending of its intensity?

- ❑ **Yes**
- ❑ **No**

If your answer is positive, do you have in mind a recent example?

Q16. Do you have an idea of the material loss than a lahar can cause depending of its intensity?

- ❑ **Yes**
- ❑ **No**

If your answer is positive, do you have in mind a recent example?

Q17. Which institutions can provide a material help?

- ❑ **Local institutions (villages, Rt, Rw)**
- ❑ **The sub-regency**
- ❑ **The regency**
- ❑ **The province**
- ❑ **The central government**
- ❑ **International institutions**
- ❑ **Private companies**

- ❑ **Others** ____

Q18. Which form can take the financial help?

- ❑ **Solidarity funds**
- ❑ **Individual insurance policies**
- ❑ **Reserve funds devoted to cases of emergency**
- ❑ **Donations**
- ❑ **Others** ____

Q19. How does the financial compensation work (from the national level to the victims)?

Q20. How could the financial responses to lahar damages be improved?

With respect to the prevention and to decisions to prevent and reduce the risks:

Q21. Are you informed on the safety measures that are to follow in case of a lahar?

- ❑ **Yes**
- ❑ **No**

Q22. Which means are currently used to disseminate information on lahar risks?

Q22a. How the information is provided?

	Yes	No	If your answer is positive, please mention the frequency of use
Pamphlets			
Posters			

Evacuation simulation			
Public meetings			
Radio			
Television			
Press			
Others			

Q22b. Where the information is provided?

	Oui	Non	Si oui, fréquence
In schools			
In public places			
In work places			
In health centers			
In mosques			
In police stations			
At home			
Associations (sport, politics)			
Others			

Q22c. When the information is provided to the following people?

	Date	Frequency
Population in vulnerable or isolated areas		
Whole population		
Children, Students		
Health workforce		
Army and Police		
Local authorities		
Others		

Q23. What are the implications of the local population beliefs on the diffusion and the assimilation of the information?

Q24. If you had financial and technical means, what would you propose to reduce lahar risk and its consequences?

In this section, we will discuss of lahar risk management and decision taking.

Q25. With which institutions are you working with in order to get information on lahar risks?

Q26. Could you mention the relationships you have with these institutions that manage risk? Which one is the most important for you? Why?

Q27. Do you think that the relationships between the different institutions in charge of the risk are coherent? Why? What is the position of these institutions regarding risk management?

Q28. Among the projects you are involved in so far, which are the main obstacles that you have identified?

Q29. Among the different projects you are involved in, which are the best results that you have obtained? Can you rank them starting from the most important?

Project

Which solutions have been implemented to face the risks produced by the lahars? Have they been efficient?

Q1. Projects

Name of the project(s)	
What are the objectives? (Zoning, risks reduction…)	
Financing: Who? How? Beginning? Cost?	
What are the (highest-priority) challenges? (Agricultural, commercial and industrial activities, houses, public infrastructure, facilities, networks, environment…)	
Which physical and monetary indicators are used to measure the effective impact of the project(s)?	

Q2. Preparation and planning

Can you describe the location of the equipped areas?	
Which type of preparation has been carried out?	
Do the project(s) have an impact on the creation or the modification of planning schemes?	

Q3. Population and stakeholders

Can the population receive support in case of crisis?	
What are the stakeholders' participation on the project(s)?	
Are they motivated by the project(s)?	

References

[1] IPCC (Intergovernmental Panel on Climate Change). Fourth Assessment Report (AR4), Climate Change 2007: Impacts, in: M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, C.E. Hanson (Eds.), Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, 2007.

[2] I. Alcántara-Ayala, Geomorphology, natural hazards, vulnerability and prevention of natural disasters in developing countries, Geomorphology 47 (2002) 107–124.

[3] C. Cohen, E.D. Werker, The political economy of "natural" disasters, J. Confl. Resolut. 52 (6) (2008) 795–819.

[4] D. Henstra, G. McBean, Canadian disaster management policy: moving toward a paradigm shift? Can. Public Policy/Anal. Polit. 31 (3) (2005) 303–318.

[5] D.A. McEntire, Triggering Agents, Vulnerabilities and disaster reduction: towards a holistic paradigm, Disaster Prev. Manag. 10 (3) (2001) 189–196.

[6] D.S. Mileti, Disasters by Design: A Reassessment of Natural Hazards in the United States, Joseph Henry Press, Washington, DC (1999), p. 376.

[7] P. O'Keefe, K. Westgate, B. Wisner, Taking the naturalness out of natural disasters, Nature 260 (1976) 566–567.

[8] H.M. Füssel, Vulnerability: a generally applicable conceptual framework for climate change research, Glob. Environ. Change 17 (2) (2007) 155–167.

[9] D. Alexander, Confronting Catastrophe: New perspectives on natural disasters, Terra Publishing, England (2000), p. 7–22 (chapter 2, Definitions).

[10] D. Strömberg, Natural Disasters, economic development, and humanitarian aid, J. Econ. Perspect. 21 (3) (2007) 199–222.

[11] R.C. de Loë, D. Armitage, R. Plummer, S. Davidson, L. Moraru, From government to governance: a state-of-the-art review of environmental governance, Final report, prepared for Alberta environment, environmental stewardship, environmental relations, Rob De Loë Consulting Services, Guelph, Ontario, 2009, p. 67.

[12] D. Bakkour, Un essai de définition du concept de gouvernance, WP LAMETA, "Études et synthèses" series, ES no. 2013–05, 2013, p. 40 ⟨http://www.lameta.univ-montp1.fr/Documents/ES2013-05.pdf⟩.

[13] B.C. Chaffin, H. Gosnell, B.A. Cosens, A decade of adaptive governance scholarship: synthesis and future directions, Ecol. Soc. 19 (3) (2014) 56, http://dx.doi.org/10.5751/ES-06824-190356.

[14] L. Gunderson, S. Light, Adaptive management and adaptive governance in the everglades ecosystem, Policy Sci. 39 (4) (2006) 323–334.

[15] F.H. Norris, S.P. Stevens, B. Pfefferbaum, K.F. Wyche, R.L. Pfefferbaum, Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness, Am. J. Community Psychol. 41 (2008) 127–150.

[16] D. Baker, K. Refsgaard, Institutional development and scale matching in disaster response management, Ecol. Econ. 63 (2007) 331–343.

[17] C.S. Holling, From complex regions to complex worlds, Ecol. Soc. 9 (1) (2004) 11.

[18] P. Olsson, Building Capacity for Resilience in Social-Ecological Systems (PhD thesis), Stockholm University, 2003.

[19] T. Dietz, E. Ostrom, P.C. Stern, The Struggle to govern the commons, Science 302 (2003) 1907–1912.

[20] C. Folke, T. Hahn, P. Olsson, J. Norberg, Adaptive governance of social-ecological systems, Annu. Rev. Environ. Resour. 30 (2005) 441–473.

[21] R. Djalante, Adaptive governance and resilience: the role of multi-stakeholder platforms in disaster risk reduction, Nat. Hazards Earth Syst. Sci. 12 (2012) 2923–2942, http://dx.doi.org/10.5194/nhess-12-2923-2012.

[22] R.D. Kusumastuti, Z.A. Viverita, L. Husodo, D.N. Suardi, Danarsari, developing a resilience index towards natural disasters in Indonesia, Int. J. Disaster Risk Reduct. 10 (2014) 327–340.

[23] J. March, Exploration and exploitation in organizational learning, Organ. Sci. 2 (1) (1991) 71–87.

[24] J. March, J. Olsen, Elaborating the 'New Institutionalism', WP No.11, Center for European studies, 2005 ⟨http://unesco.amu.edu.pl/pdf/olsen2.pdf⟩.

[25] S. Lhomme, G. Djament-Tran, Penser la résilience urbaine. In: G. DjamentTran, M. Reghezza-Zitt (Ed.), Résiliences urbaines: les villes face aux catastrophes, coll Fronts pionniers, Paris, Editions Le Manuscrit, 2012, pp. 13–46.

[26] G.C. Gallopín, Linkages between vulnerability, resilience, and adaptive capacity, Glob. Environ. Change 16 (3) (2006) 293–303.

[27] F. Miller, H. Osbahr, E. Boyd, F. Thomalla, S. Bharwani, G. Ziervogel, B. Walker, J. Birkmann, S. van der Leeuw, J. Rockstrom, J. Hinkel, T. Downing, C. Folke, D. Nelson, Resilience and vulnerability: complementary or conflicting concepts? Ecol. Soc. 15 (3) (2007) (Article no. 11).

[28] C.S. Holling, Resilience and stability of ecological systems, Annu. Rev. Ecol. Syst. 4 (1973) 23.

[29] F. Berkes, Understanding uncertainty and reducing vulnerability: lessons from resilience thinking, Nat. Haz. 41 (2) (2007) 283–295.

[30] United Nations International Strategy for Disaster Risk Reduction (UNISDR), Hyogo framework for 2005–2015: building the resilience of nations and communities to disasters, 2005, pp. 1–25.

[31] C. Kuhlicke, A. Steinführer, Social capacity building for natural hazards, a conceptual frame. CapHaz-Net WP1 Report, Helmholtz Centre for Environmental Research–UFZ, Leipzig, 2010, p. 50.

[32] R. Djalante, C. Holley, F. Thomalla, Adaptive governance and managing resilience to natural hazards, Int. J. Disaster Risk Sci. 2 (2011) 1–14, http://dx.doi.org/10.1007/s13753-011-0015-6.

[33] N. Adger, T. Hughes, C. Folke, S. Carpenter, J. Rockstrom, Social-ecological resilience to coastal disasters, Science 309 (2005) 1036–1042.

[34] UNDP (United Nations Development Program) Indonesia, Lessons learned: Indonesia's partnership for disaster risk reduction, the national platform for DRR and the university forum, Jakarta: United Nations Development Program—Indonesia, 2008 ⟨http://www.undp.or.id/pubs/docs/Lessons%20Learned%20Indonesias%20partnership%20for%20Disaster%20Risk%20Reduction.pdf⟩.

[35] J.C. Thouret, F. Lavigne, K. Kelfoun, S. Bronto, Toward a revised hazard assessment at Merapi volcano, Central Java, J. Volcanol. Geotherm. Res. 100 (2000) 479–502.

[36] F. Lavigne, J.C. Thouret, B. Voight, H. Suwa, A. Sumaryono, Lahars at Merapi volcano, J. Volcanol. Geotherm. Res., 100, an overview, Central Java (2000), p. 423–456.

[37] C. Newhall, S. Bronto, B. Alloway, N.G. Banks, I. Bahar, M.A. DelMarmol, R. D. Hadisantono, R.T. Holcomb, J. McGeehin, J.N. Miksic, M. Rubin, S.D. Sayudi, R. Sukhyar, S. Andreastuti, R.I. Tilling, R. Torley, D. Trimble, A.D. Wirakusumah, 10,000 years of explosive eruptions on Merapi volcano, central Java: archaeological and modern implications, J. Volcanol. Geotherm. Res. 100 (2000) 9–50.

[38] Ph. Jousset, J. Pallister, Surono, Special issue "Merapi eruption",, J. Volcanol. Geotherm. Res. 261 (2013) 387.

[39] P. Surono, P. Jousset, J. Pallister, M. Boichu, F. Buongiorno, A. Budisantoso, F. Costa, S. Andreastuti, F. Prata, D. Schneider, L. Clarisse, H. Humaida, S. Sumarti, C. Bignami, J. Griswold, S. Carn, C. Oppenheimer, F. Lavigne, The 2010 explosive eruption of Java's Merapi volcano–A '100-year' event",, J. Volcanol. Geotherm. Res. 241–242 (2012) 121–135.

[40] E.T.W. Mei, F. Lavigne, A. Picquout, E. De Bélizal, D. Brunstein, D. Grancher, J. Sartohadi, N. Cholik, C. Vidal, Lessons learned from the 2010 evacuations at Merapi volcano, J. Volcanol. Geotherm. Res. 261 (2013) 348–365.

[41] F. Lavigne, J.C. Thouret, Sediment transportation and deposition by rain-triggered lahars at Merapi Volcano, Central Java, Indonesia, Geomorphology 49 (2002) 45–69.

[42] E. De Bélizal, F. Lavigne, D. Sri Hadmoko, J.P. Degeai, G. Aria Dipayana, B. Wahyu Mutaqin, M. Aris Marfai, M. Coquet, B. Le Mauf, A.K. Robin, C. Vidal, N. Cholik, N. Aisyah, Rain-triggered lahars following the 2010 eruption of Merapi volcano, Indonesia: a major risk, J. Volcanol. Geotherm. Res., 261, (2013) 330–347.

[43] A. Solikhin, J.C. Thouret, S.C. Liew, A. Gupta, D. Sri Sayudi, J.F. Oehler, Z. Kassouk, High-spatial resolution imagery helps track the effects and deposits of the large (VEI 4) Merapi Volcano eruption, Bull. Volcanol. 77 (2010) 20, http://dx.doi.org/10.1007/s00445-015-0908-0.

[44] J.C. Tayag, R.S. Punongbayan, Volcanic disaster mitigation in the Philippines: experience from Mt Pinatubo, Disasters 18 (1994) 1–15.

[45] M. Rivera, J.C. Thouret, J. Marino, R. Berolatti, J. Fuentes, Characteristics and management of the 2006–2008 volcanic crisis at the Ubinas volcano (Peru), J. Volcanol. Geotherm. Res. 198 (2010) 19–34.

[46] E. De Bélizal, F. Lavigne, J.C. Gaillard, I. Pratomo, J.C. Komorowski, The 2007 eruption of Kelut volcano (East Java, Indonesia): phenomenology, crisis management and social response, Geomorphology 136 (1) (2012) 165–175.

[47] V. Ngoc Chau, J. Hollanda, S. Cassells, Institutional structures underpinning flood management in Vietnam, Int. J. Disaster Risk Reduct. 10 (2014) 341–348.

[48] D. Bonet, Réflexions sur les relations interorganisationnelles: du dépassement de l'antagonisme conflit-coopération à l'émergence de nouvelles démarches collaboratives, HDR, Centre de Recherche sur le Transport et la Logistique CRET-LOG, Université de la méditerranée, 2008.

[49] R. Ghiglione, A. Landré, M. Bromberg, P. Molette, L'analyse automatique des contenus, Dunod, Paris, 1998.

[50] M. Hajer, W. Versteeg, A decade of discourse analysis of environmental politics: achievements, challenges, perspectives, J. Environ. Policy Plan. 7 (3) (2005) 175–184.

[51] G. Enjolras, R. Kast, J.C. Thouret, M. Nagata, B. Prihatminingtyas, J. Uchuchoque, Management systems against flood hazard and risk: the Indonesian and Peruvian experiences, in: Contributed paper to the IWA-WCE World Congress on Water Climate and Energy, Dublin, Ireland, May 13–18, 2012.

[52] E.T.W. Mei, Gestion des évacuations lors des crises volcaniques : étude de cas du volcan Merapi, Java, Indonésie, (PhD thesis (unpublished)), Laboratory Espaces, sociétés, aménagement, Laboratory géographie physique "Pierre Birot", Université Paris 1, 2013, p. 333.

[53] A. Arfan, Prospects and constraints of general insurance business in the islamic law perspective, De Jure 1 (1) (2009) 63–70.

[54] S. Surminski, D. Oramas-Dorta, Flood insurance schemes and climate adaptation in developing countries, Int. J. Disaster Risk Reduct. 7 (2014) 154–164.

[55] J.R. Eiser, A. Bostrom, I. Burton, D.M. Johnston, J. Mc Clure, D. Paton, J.V.D. Pligt, M.P. White, Risk interpretation and action: a conceptual framework for responses to natural hazards, Int. J. Disaster Risk Reduct. 1 (2012) 5–16.

[56] F. Lavigne, B. De Coster, N. Juvin, F. Flohic, J.C. Gaillard, P. Texier, J. Morin, J. Sartohadi, People's behaviour in the face of volcanic hazards: perspectives from Javanese communities, Indonesia, J. Volcanol. Geotherm. Res. 172 (2008) 273–287.

[57] S. Jenkins, J.C. Komorowski, P.J. Baxter, R. Spence, A. Picquout, F. Lavigne, P. Surono, The Merapi 2010 eruption: an interdisciplinary impact assessment methodology for studying pyroclastic density current dynamics, J. Volcanol. Geotherm. Res. 261 (2013) 316–329.

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